



Onboard Science for the Europa Clipper Mission

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Europa Clipper Science Challenges

- Limited onboard storage
- Limited downlink
- Limited power
- Limited time
 - Small number of flybys
 - Anticipated radiation faults and recovery time

Desire for Onboard Science

- Downlink best (decisional) data early to enable planning for next flyby petal
- Science autonomy spectrum:



Summarize



Prioritize



Increase collection



Retask



Onboard Science to Support Science Themes

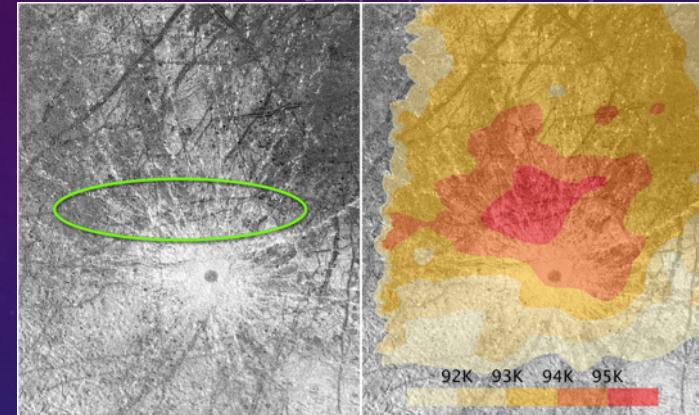
1. Thermal anomaly detection

- Cryovolcanism
- Recent resurfacing

2. Spectral analysis

- Surface organics
- Plume deposits

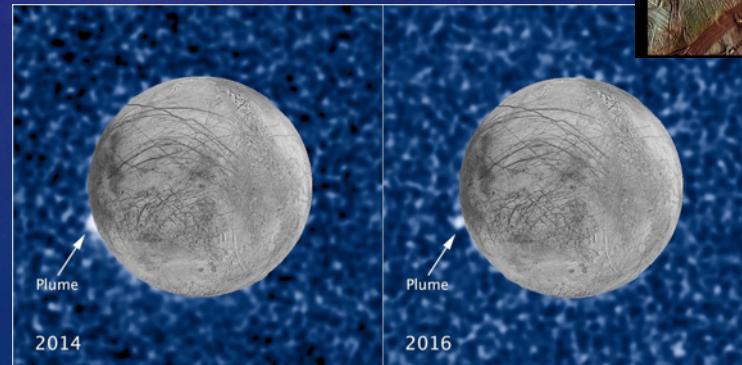
3. Plume detection



Galileo



Galileo



Hubble

Image credits:

Thermal/plume: NASA, ESA, W. Sparks,
USGS Astrogeology Science Center;
Bands: NASA/JPL-Caltech/SETI Institute

1. Thermal Anomaly Detection: EO-1 Heritage



Summarize



Prioritize

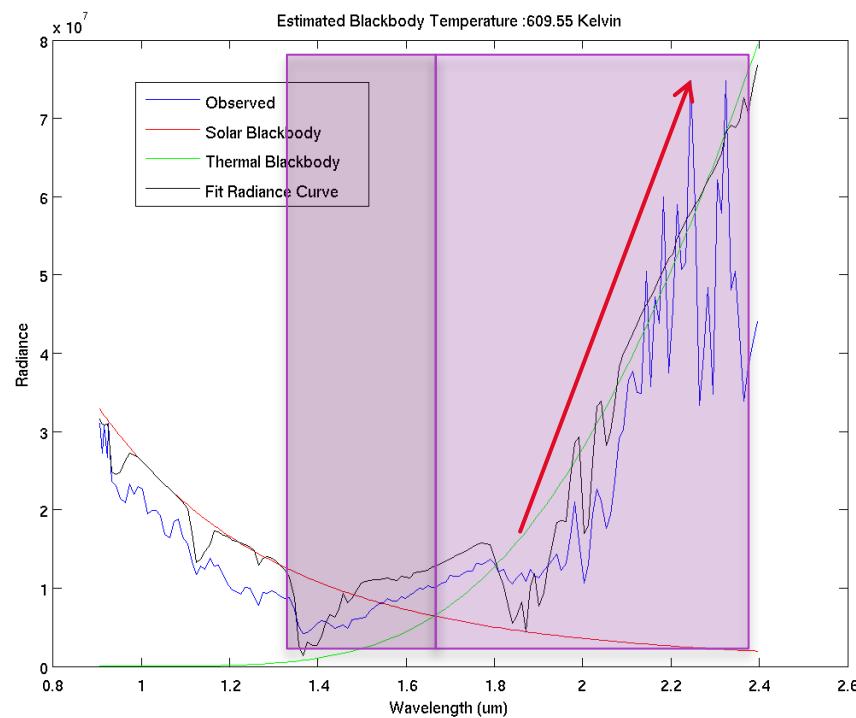
Increase
collection

Retask

ASE Onboard
Thermal Classifier
(Erebus Day)



Description	Measure
H1: Hot radiance minimum and pixel not noisy	$0.625 < 1.65 \mu\text{m}$, $2.25 \mu\text{m}$, & $2.28 \mu\text{m} < 750$
H2: Min. slope for trigger?	Slope G > 0.13558 G=1.4 for DNs
H3/E3: No $2.28\mu\text{m}$ spike	$(2.28\mu\text{m} + 1.65\mu\text{m})/2 < 2.25\mu\text{m} * 1.2$
E1: Extreme radiance min.?	$0.625 < 1.25 \mu\text{m}$, $1.65 \mu\text{m}$, & $2.28 \mu\text{m} < 750$
E2: Spectrum shape	$2.28 \mu\text{m} > 1.65 \mu\text{m}/2$



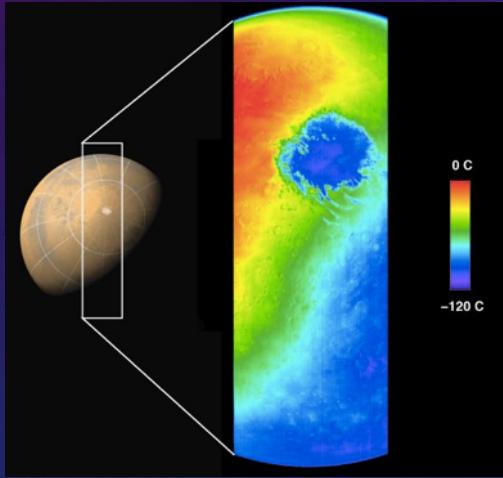
- Complete Hyperion Product = ~ 1 Gb via X-band available within day(s)
- Thermal summary = ~ 10 Kb via S-band available within hour(s)
- Thousands of summary products executed.

1. Thermal Anomaly Detection: THEMIS Heritage

Summarize

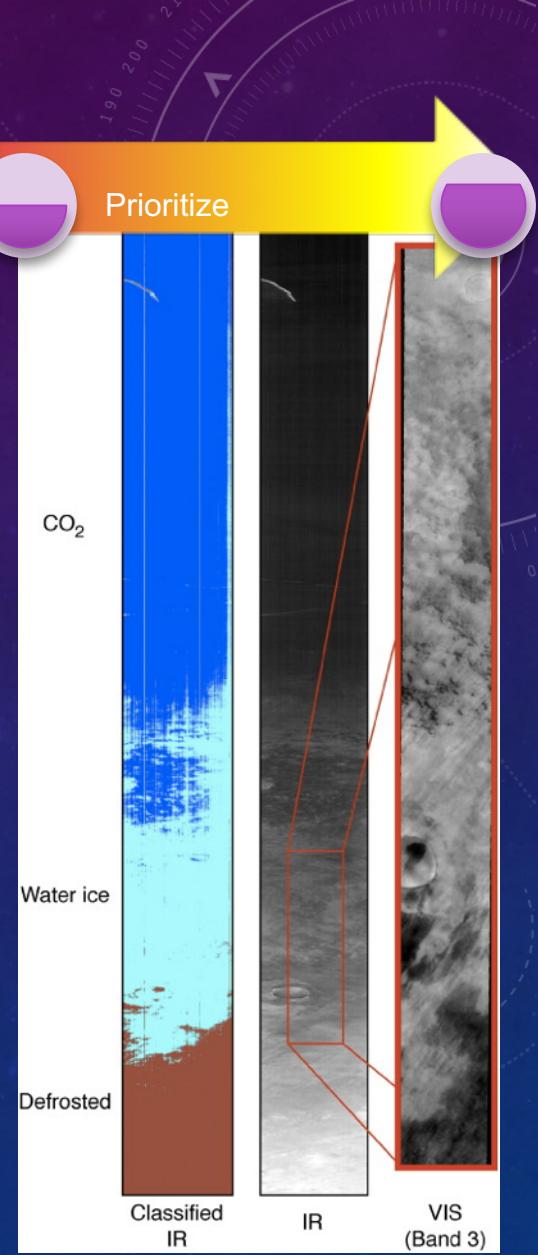
Prioritize

- Thermal anomaly detection
 - 14,856 THEMIS nighttime images
 - 143 images > 240K (band 9, 12.57 um)
 - Synthetic positives: 100% detection
 - Polar cap tracking
 - Led to first discovery of north polar water ice annulus in THEMIS data [Wagstaff et al., 2008]
 - Europa: E-THEMIS



Mars south polar cap

Image credit: Mars Odyssey team, ASU, JPL, NASA



Mars north polar cap

R. Castaño et al., 2007. *Knowledge Discovery and Data Mining*.
K. Wagstaff et al., 2008. *Planetary and Space Science*.

2. Spectral Analysis: EO-1 Heritage

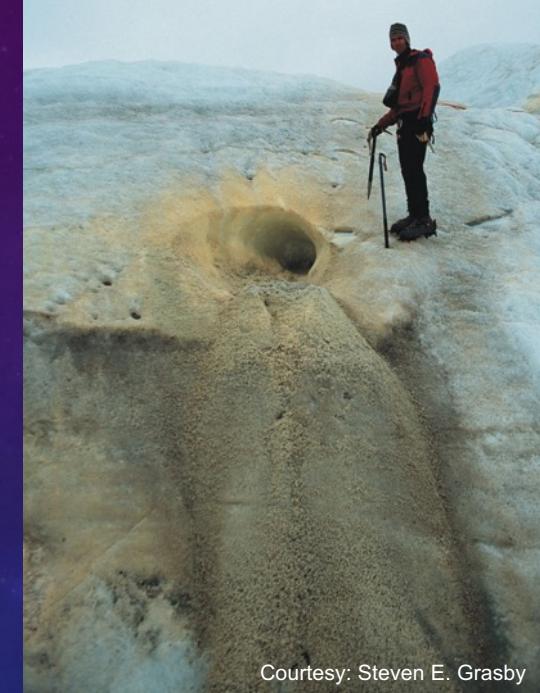
- Borup Fiord sulfur springs
- Biosignature analog site for Europa
- Detect and track from orbit (EO-1)
 - Support vector machine classifier
 - 26 detections as of May 31, 2016



EO-1 image
(Hyperion)

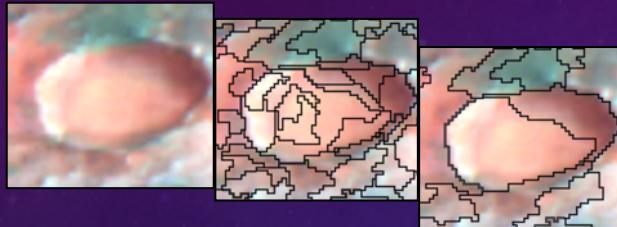


Sulfur detection (yellow)



- Europa: MISE

2. EO-1 Onboard Spectral Analysis

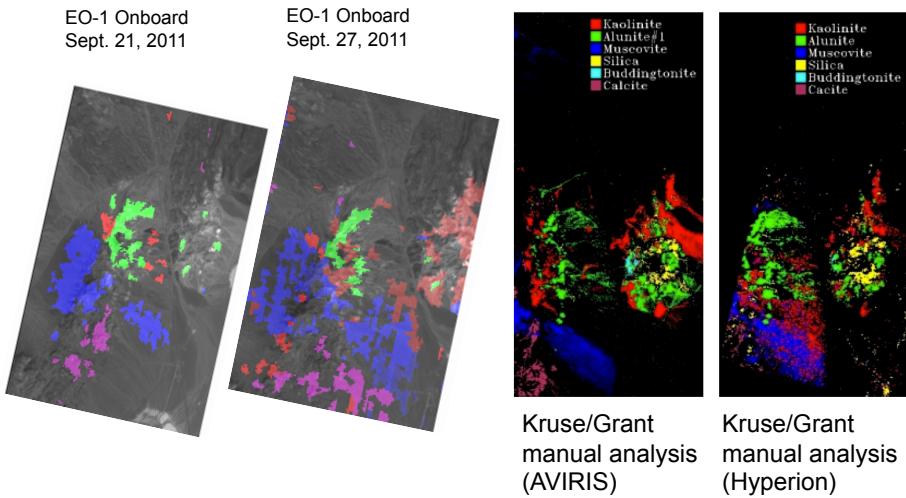


Superpixel segmentation
+

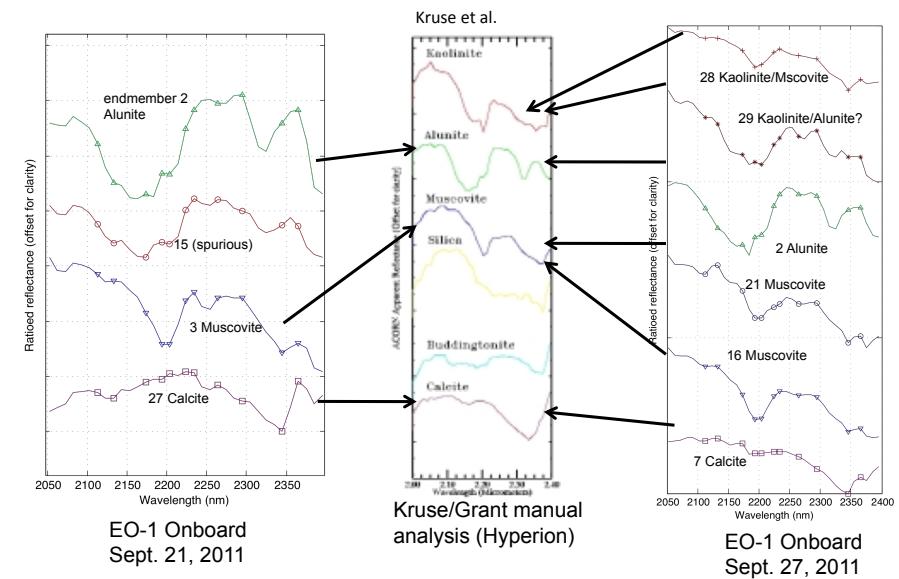
Sequential maximum angle
convex cone (SMACC)
endmember extraction

Results from onboard EO-1
(9/2011)

Repeatability: maps



Repeatability: detections



3. Plume Detection: Dust Devil (Change) Detection

Summarize

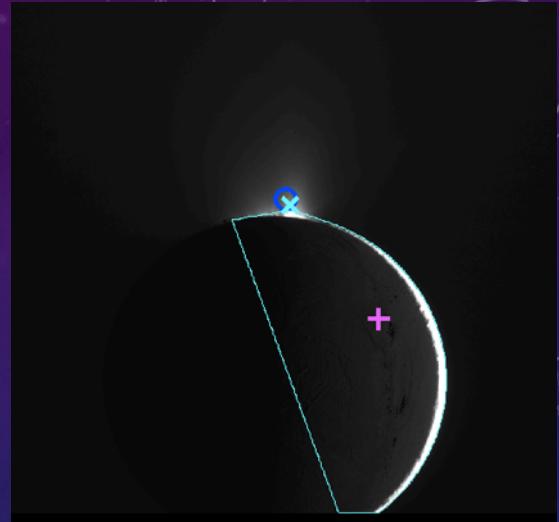
Prioritize



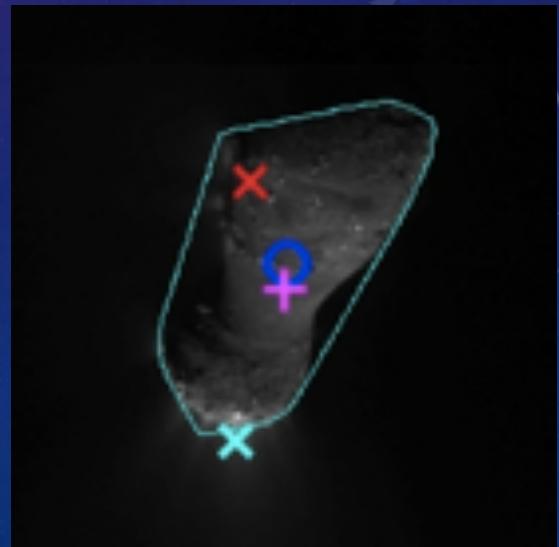
- Analyze sequence of images for motion detection
- Operationally qualified on Mars Exploration Rovers in 2008
- Consumes no data volume when no activity detected
- Achieved significant data reduction in image sequence data volume

3. Plume Detection: Moons and Comets

- Real-time detection using a convex hull
 - Not restricted to spherical bodies
 - Enceladus (Cassini, 756 images)
 - Increased detections by 63%
 - Decreased false detections by 27%
 - Comet Hartley 2 (EPOXI, 45 images)
 - Perfect localization of plume
 - Europa: EIS/UVIS



Enceladus (Cassini ISS)



Hartley 2 (EPOXI MRI)

Coordinated Onboard Science

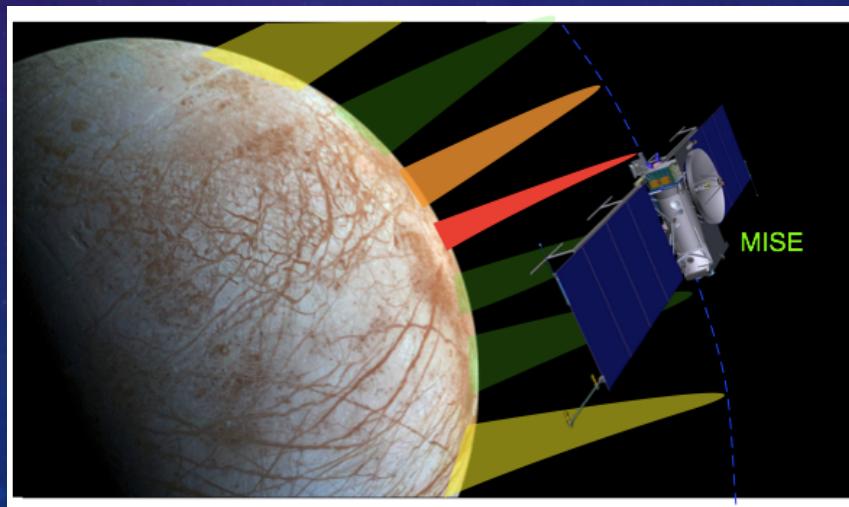


Summarize

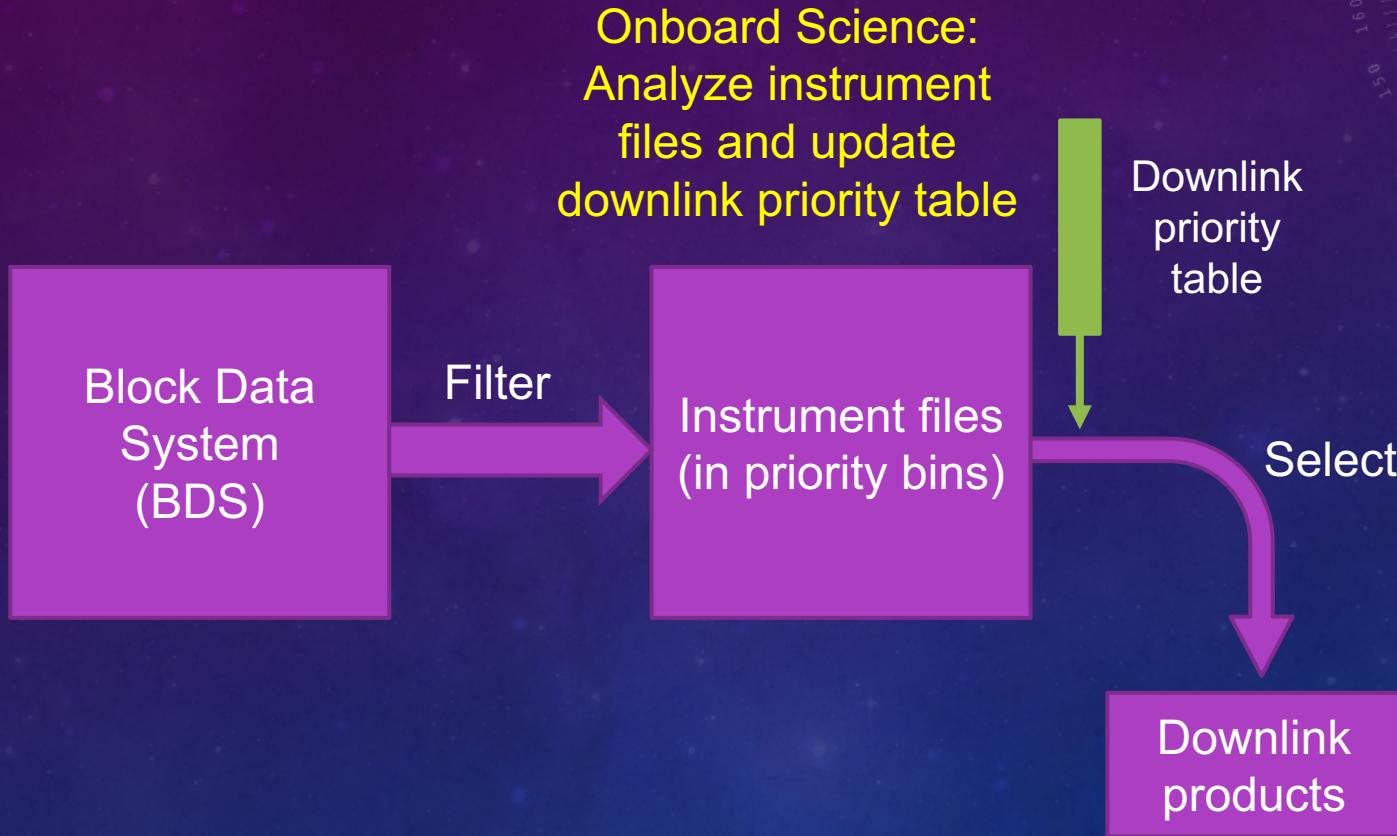


Prioritize

- AEGIS: Detect targets in NavCam, collect data with ChemCam
 - In operational use by MSL; included in Mars 2020
- Europa: Detect features in E-THEMIS, adjust priorities of MISE data



Integration on Europa Clipper



At what cost?

- Resources: Processor, Memory, Time
- Heritage
 - EO-1: 12 MHz, no FPU, 128 MB RAM
 - Mars Odyssey: 33 MHz, 128 MB RAM
 - MER: 33 MHz, 128 MB RAM
 - MSL: 200 MHz, 256 MB RAM
 - Note: Onboard science modules operate in a fraction of these totals

Agile Science Concept

- Onboard event/feature detection
 - Faster than with ground in the loop; vital for transient or unpredictable phenomena
- Generation of a response (re-planning)
 - Weigh benefits against costs (time, power, data)
- Execution of response to collect new data
 - Observing at higher resolution or data rate
 - Observing with another instrument



Summarize



Prioritize



Increase
collection



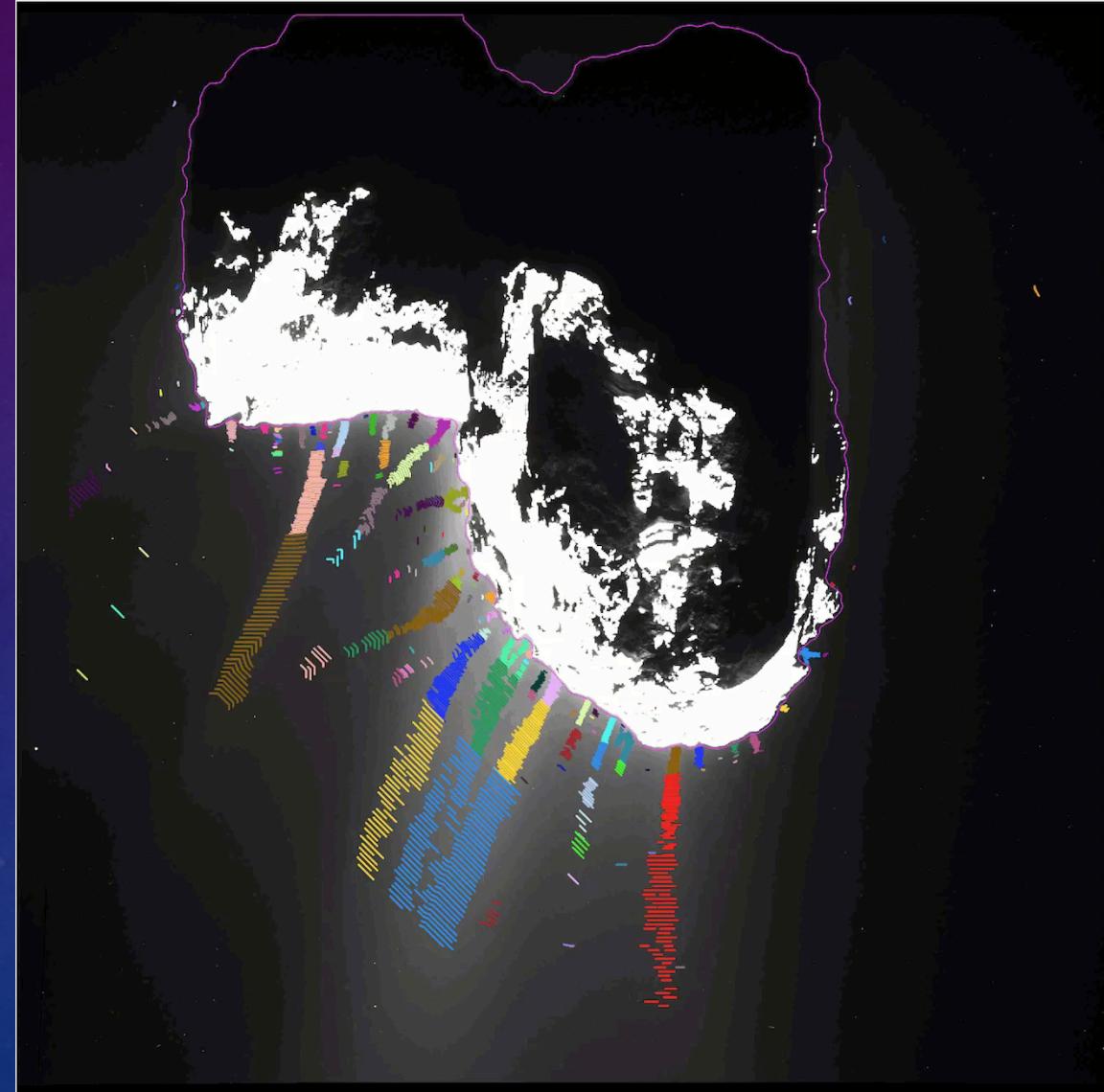
Retask



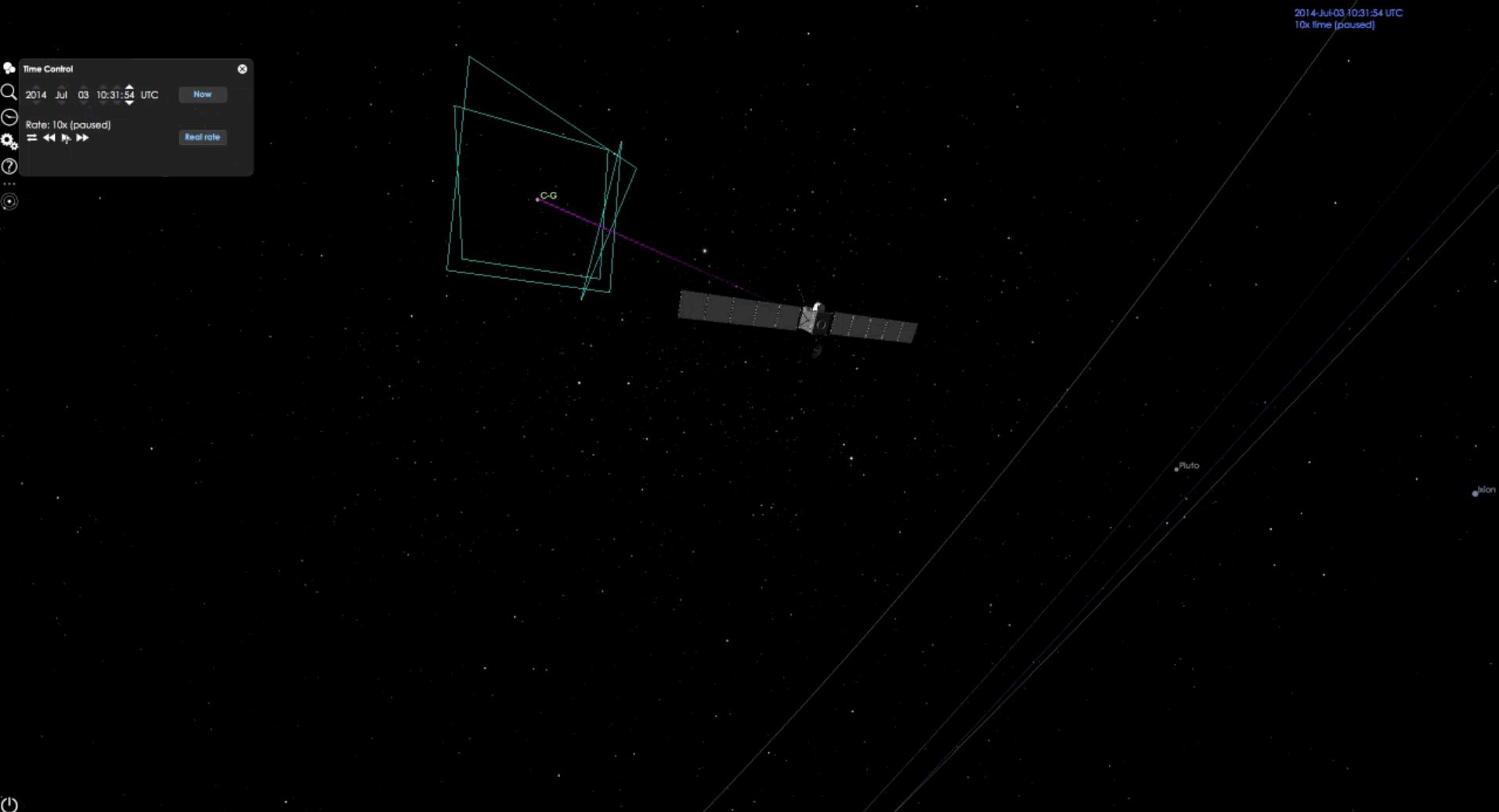
Plume Tracking in OSIRIS/Rosetta images

- Highly non-convex body
- Significant illumination issues
- Noisy data
- Still in development

See Brown et al. 2017
IJCAI AI Space



End Vision: Detect plumes during flyby and task/point narrow field of view instrument



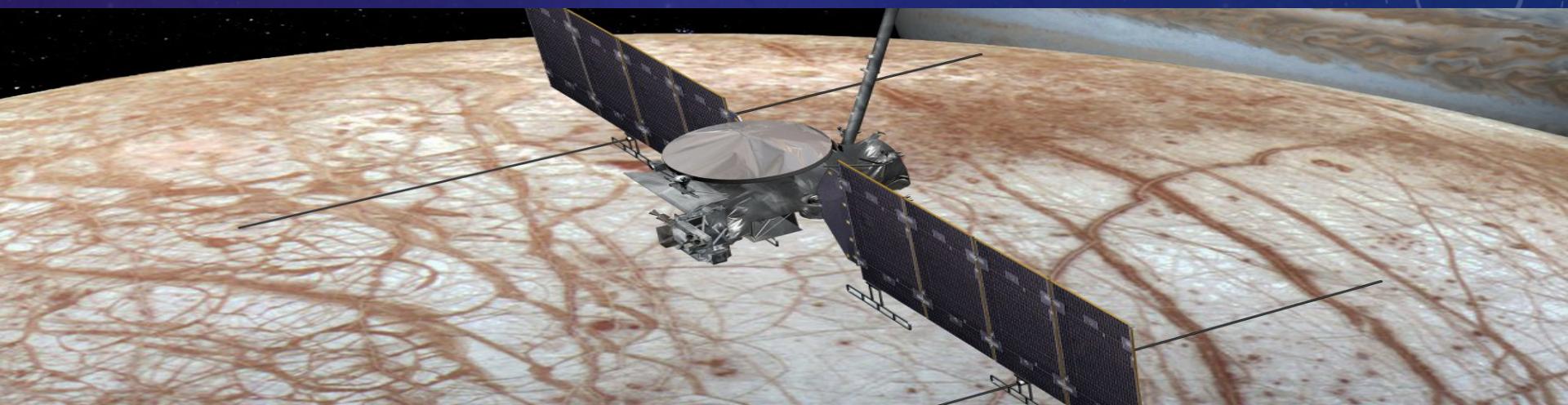
Current Status: Plume detection for convex bodies and geometry aware re-planning in VxSIM [Chien et al. 2016]

Flight Experience

- Earth Observing 1
- IPEX CubeSat (Earth orbit)
- Mars Exploration Rovers
- Mars Science Laboratory rover
- Mars 2020

Onboard Science for Europa Clipper

- Methods are mature and flight-proven
- Assist in meeting mission science goals
 - Thermal anomalies, spectral anomalies, plumes
- Now is the time to evaluate possible integration paths
- Thanks: Al Cangahuala, Mitch Ingham, Bob Pappalardo, Bob Rasmussen, Peter Shames



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